GREEN HOUSE EFFECT AND GLOBAL WARMING

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Preamble

The original module 'Greenhouse effect and Global warming' was produced in 1993 under a Project entitled 'Development of Material in Chemistry on Some Current Topics of Human Concern; of the Department of Education in Science and Mathematics (DESM) of the National Council for Educational Research and Training (NCERT). A decade later, specially in the perspective of the 'Kyoto Protocol' the module has been revised and wherever possible new data and information added

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PREFACE

The day to day relevance of Chemistry to the critical issues facing the human kind do not often get highlighted substantially in Chemistry textbooks themselves because of several constraints connected with textbook development Thus, with the objective of generating greater awareness of the role of Chemistry in such critical issues, the Department of Education in Science and Mathematics (DESM) of the National Council of Educational Research and Training (NCERT) has undertaken a project of "Development of Materials in Chemistry on some Current Topics of Human Concern". Under this project, it is proposed to develop booklets/modules on selected topics for teachers and students of senior secondary classes The booklets could also be of interest to others who wish to know about these topics. The first module under the project, developed last year, was on the phenomenon of depletion of ozone layer and its consequences. The present module is the second product of this project.

The booklet deals with the phenomenon of greenhouse effect and its major consequence -global warming The booklet starts out by explaining the phenomenon of greenhouse effect and then goes on to discuss the consequences of global warming This is followed by a brief discussion of the so called "greenhouse gases" – carbon dioxide, methane, nitrous oxide, ozone and other phenomena such as the presence of "aerosols" and the "feedback phenomenon" that influence the greenhouse effect. Finally, the booklet discusses briefly the steps that the international community is taking - India included, to reduce the greenhouse effect.

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In 1896, the famous Swedish Chemist Svante Arrhenius resolved a long standing mystery: how does the earth's atmosphere maintain the planet's relatively warm temperature, when oxygen (O_2) and nitrogen (N_2), which constitute 99% of the atmosphere do not absorb heat from the infra red (I.R) radiation emitted from the earth back to space. Arrhenius discovered that carbon dioxide (CO_2), which makes up only a tiny fraction of the atmosphere, could trap enough of the escaping heat to warm the planet's surface Furthermore, he realized that burning of coal, oil and natural gas was raising the concentration of CO_2 in the atmosphere. Arrhenius predicted that a doubling of CO_2 could warm the planet by more than 10° F, a prediction that is considered reasonable by scientists even today

Now well known as the "greenhouse effect" * - this warming phenomenon was given little attention, until scientists Keeling and Revelle of the Scripps Institute of Oceanography at La Jolla California began to study the "carbon-cycle" and carefully recorded the atmosphere's carbon dioxide in 1958 - on the slope of the mountain Mauna Loa in Hawaii. They not only recorded the annual C-cycle but also documented a steady rise of CO_2 due to human activities (1) Years later, at the 1998 world economic forum in Davos, Switzerland, the CEO's of world 1000 largest corporations voted climatic change as the most critical problem facing huminity (2).

Gradually it has been established that certain atmospheric emissions resulting from anthropogenic causes (i.e. due to various human activities), are unambiguously responsible for this warming effect -more commonly known as "global warming" - a phenomenon which has now taken the proportion of an environmental crisis These anthropogenic emissions appropriately called as "greenhouse gases", due to their ability to trap heat, include carbon dioxide (CO_2) - the necessary product of combustion of fossil fuels; chloroflurocarbons (CFCs) released from refrigeration processes and halons from fire fighting systems; methane (CH_4) from anaerobic digestion of organic matter; nitrous oxide (N_2O) from increase use of chemical fertilisers, etc. The contribution of CO_2 to global warming is found roughly to be 50%, the other half is due to the other gases. (Table 1)

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* A greenhouse is a special enclosure used for growing/ maintaining plants at a specified temperature and humidity. In the countries where winter temperatures are normally rather low, a greenhouse is made with roofs and sides principally of glass plants obtain light and can also be watered. Because of the ability of a greenhouse to remain warm due to heat trapped by its glass enclosure - the analogous atmosphere warming due to trapped heat has been called the "greenhouse effect".

Table I

CONTRIBUTION TO GLOBAL WARMING THROUGH EMISSIONS

GAS	PERCENTAGE
CO_2	55%
CFCs	24%
CH_4	15%
N_2O	6%

Source: ZUPER, P.S. Economic Consideration Entry Fray Over Global Climatic Change Policies. Chem. Engg News 69. (April 1991) 7

In addition to the gases mentioned in Table 1, O_2 and water vapour etc. present in the atmosphere also contribute to the effect. Though CO_2 is considered the main greenhouse gas, as obvious from Table 1, the other greenhouse gases, although present only in trace amounts, have longer atmospheric life time and are therefore much more effective than CO_2 in their radiative absorption potential (i.e. heat trapping capacity) (Table 2) They are consequently dangerous even at their trace concentration levels. In addition, positive feedback effects (page 33) add to global warming (3)

It needs to be pointed out that, though commonly carbondioxide is considered to be the principal greenhouse gas, but actually it is not - water vapour is The amount of carbon dioxide in air is pale in significance, compared to water vapour, which ranges between 1 and 4%, depending on temperature and humidity But of course, we have no control over the amount of water in the atmosphere, though we may have at least a little control over the amount of carbon dioxide and the other greenhouse gases

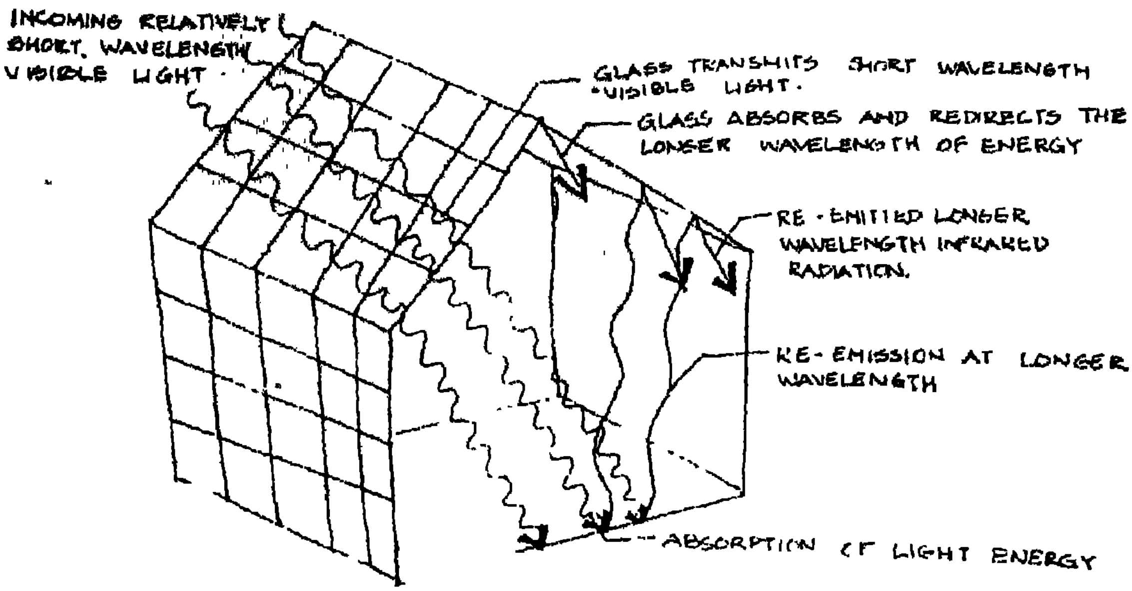

INCOMING RELATIVELY SHORT, WAVELENGTH VISIBLE LIGHT.
GLASS TRANSMITS SHORT WAVELENGTH VISIBLE LIGHT.
GLASS ABSORBS AND REDIRECTS THE LONGER WAVELENGTH OF ENERGY
RE-EMITTED LONGER WAVELENGTH INFRARED RADIATION.
RE-EMISSION AT LONGER WAVELENGTH
ABSORPTION OF LIGHT ENERGY

Table 2

Chemical Species	Chemical Formula	Av. Residence Time (Year)	Global Av. Mixing Ratio (ppb)	Radiative Abs. Pot. Rel. To CO_2*
Carbondioxide	CO_2	0	339,000	1
Nitrogen Compounds	N_2O	120	300	150
	$(NO+NO_2)$	0 001	0 05	-
Chlorofluoro carbons	CF_2Cl_2	110	028	21,000
	$CFCl_3$	65	0 18	14,000
	$CHClF_2$	20	0 06	-
	CCl_4	25-50	0 13	-
Hydrocarbon and others	CH_4	5-10	1650	32
	CO	0.3	90	-
	H_2	2	560	-
Ozone (tropospheric)	O_3	0 1-0.3	25-70	2000

Source: Based on HARRIES i.e. Earthwatch. Ellis Horwood (1990) 216 pp

* Daniel R. R. The Industrial Geosphere Biosphere Programme

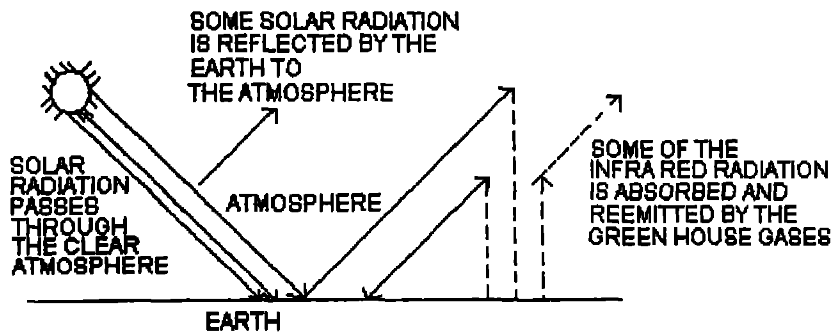
A Study of Global Change

HOW DOES THE EARTH'S ATMOSPHERE TRAP THE HEAT?

For a simple understanding of this, it is necessary to understand some basic facts about the spectroscopy of the earth's atmosphere – i e. the way in which radiation as a function of wavelength interacts with earth's atmosphere.

As is known, the amount and nature of radiation energy from a heated object depends primarily on the temperature of the object Radiations coming from the sun are mostly the visible type to which our eyes are sensitive Visible radiations pass through CO_2 in the atmosphere, with very little attenuation The radiations after penetrating the earth's atmosphere are partially absorbed by the earth's surface Since the temperature of the earth's surface is much lower than that of the sun, the type of radiation (re-radiated) from the earth is

much different from the one that it received The radiation (re-radiated) from the earth is mostly the infrared (I.R.) type - which is absorbed by molecules viz CO_2, CH_4, CFCs, N_2O, $O_3$and water vapour found in the atmosphere (Fig 2)



A SIMPLIFIED DIAGRAM ILLUSTRATING THE GREEN HOUSE EFFECT

Fig 2

As a result energy is trapped and the temperature of the earth and that of its atmosphere is found to be higher than what is expected Thus a significant rise in the amount of these greenhouse gases would obviously raise the temperature of the atmosphere

A more quantitative explanation of this effect can be given in terms of a simple relationship between temperature (T) and wave- length (λ) of the most predominant radiation of heated objects

$$\lambda \cdot T = 2900 \times 10^{-6} \text{ mK}$$

where, λ is represented in the unit of 1×10^{-6} m and temperature in K The sun radiates at an effective temperature (T) of about 6000K

Hence the most probable

$$\lambda = \frac{2900 \times 10^{-6} \text{mK}}{6000\text{K}}$$

$$= 480 \times 10^{-9} \text{ m.}$$

This wavelength corresponds to the visible range of the electromagnetic spectrum The earth radiates at an effective temperature of about 255 K. Hence, the most probable λ of radiation from the earth is·

$$\lambda = \frac{2900 \times 10^{-6} \text{mK}}{255\text{K}}$$

$= 11 \times 10^{-6}$ m

$= 11000 \times 10^{-9}$ m

Table 3

Primary I. R. Absorption Bands

Gas	Band Center ($\times 10^{-9}$m)
H_2O	2700
	6300
	20000
	40000
CO_2	4300
	15000
N_2O	7800
O_3	4700
	9600
	14100
CH_4	3300
	7700

Source: HARRIES J.E Earthwatch Ellis Howard (1990) 216pp

This wavelength corresponds to the I R region of the electromagnetic spectrum and is not perceived by the human eye The "greenhouse gases" selectively absorb I.R. radiation and it is this selective absorption that gives rise to the atmospheric temperature of the earth. Thus, if the concentration of the greenhouse gases increases in the atmosphere, the temperature of the atmosphere increases too (4)

Before discussing the outcomes of the "greenhouse effect" (GHE), it should be emphasized that the GHE (the warming of the atmosphere due to trapped heat) is a perfectly natural process In fact, without this, the earth's surface could perhaps been covered with a sheet of ice, with the surface temperature being about 33° C lower than what it is today (5) It is the enhancement to this natural GHE, resulting from anthropogenic reasons, that is becoming a concern for the human kind - since enhancement of this natural process may lead to a destabilization of the critical balance of the nature

The term greenhouse effect is used in the literature in the context of i) The "Original GHE" a phenomenon which helps keep the earth's surface from being frozen over completely (ii) The "Anthropogenic Carbon dioxide GHE" -which refers to the predicted further warming of the global surface temperature associated with presumably human-caused increase in atmospheric carbon dioxide concentration. (iii) The Augmented "Anthropogenic GHE" which refers to the observed increase in other relatively active atmospheric constituents such as methane, chlorofluorocarbons, nitrous oxide, ozone, which add to the effect of increasing carbon dioxide concentration (iv) "The Journalistic GHE" - which refers to a range of phenomena, including the augmented anthropogenic GHE, the stratospheric "ozone hole" over the Antarctica, the ultraviolet (U V) radiation at ground level, sea level changes, and other environmental changes e.g warmer winters, drought in some places, deforestation of the tropical forests. These are all embraced by one phrase - the "greenhouse effect" - now often truncated as just the "greenhouse" (6)

THE POSSIBLE EFFECTS OF GLOBAL WARMING AND GREENHOUSE EFFECT

The most direct effect of the increased trapping of heat radiation i e the greenhouse effect is "global warming". It is estimated that the average global temperature has increased by 0.6°C in the last 100 years and could go up by 1.4 to 5.8 °C in the next 100 years(7) Because this warming is not expected to be even throughout the atmosphere, atmospheric chemists anticipate that there will be suitable, yet important changes to the ways in which global atmosphere mixes, leading to changes in rainfall pattern, storminess, frequency of extreme climatological events etc While there is a general agreement as to the nature of the global warming, on the average, the regional and seasonal climatic impacts are very uncertain The green house gases live long enough in the atmosphere and therefore, it may not matter where they are released -they could soon become widely dispersed in the atmosphere and influence the climate globally, even though the gradient will alter the pattern of winds and precipitation distribution regionally (8)

This increase in global atmospheric surface temperature would have two consequences to the total volume of the oceans - first, the melting of ice from higher altitudes and latitudes will add to the total volume of oceans, and second, the volume of sea water will increase due to thermal expansion It is found that the Doknani glacier in the Garhwal Himalayas has

retreated 66 ft in 1988 whereas the Gangotri glacier is retreating 98 ft/year At this rate, scientists predict a possible loss of central and eastern Himalayan glaciers by the end of the 21st century As a Consequence of the melting of the glaciers, sea level will rise, leading to inundation of lower lying areas, drown coastal marshes and wetlands thus bring about ecological changes The rise in the sea level may lead to excess floods, increase the salinity of rivers, bays and aquifiers throughout the world This could also lead to damage of infrastructure including harbours, coastal defence systems, roads etc (9)

Nearly one third of the human population lives with 60kmof the coast and resides on land that could be lost due to sea level rise. Thus lower latitude coastlines found in developing countries (including India) are particularly vulnerable to sea level rise In the last three decades, rising ocean levels have flooded 18,5000 acres of mangrove forest at sunderbans in West Bengal. Tropical storms may occur with greater intensity, and could penetrate further inland due to sea level rise, resulting in greater loss of life Flooding of low lying coastal areas of the countries such as India, Bangladesh, China, Egypt, by rise of the sea level could lead to a new breed of "environmental refugees". If such predictions come out to be correct, the greatest ecological damage from global warming will hit the countries that have the least resources to deal with them (10)

A report from the United Nation's Food and Agricultural Organisation (FAO) stated that a rise in the earth's temperature would push the climate zone and ecosystems of the middle latitudes between 200 to 700 km closer to the poles over the next 200 years enabling crops to be grown in areas which are too cold. But the major beneficiaries of this move would be temperate zone countries such as the U S and Canada, which already produce much of the world's grain. Unless crops and farming systems can be adapted to changing conditions arid and semi arid nations are likely to suffer.

Among other risks, increased cloud cover could reduce photo-sysnthesis and cause a drop in plant productivity, reduced snow cover at high altitudes could expose winter crops to more frequent frosts, floods, droughts and intense mid season dry spells could become more common as would hurricanes and cyclones More variable rainfall and an increase in plant evapo-transpiration could reduce the effectiveness of some irrigation schemes.

Fish stock could also be affected in unpredictable ways Global warming could lead to a shift in the production and distribution of plankton and cause changes in marine habitats

Inland fishing could also be affected since drought, floods and higher temperature affect such activities (11).

Most global warming models predict that increase in temperature will be largest in the higher altitudes in winter and during the night In consequence rainfall patterns will alter probably with more precipitation in coastal regions and less in continental interiors The interaction of these elements will largely determine how pattern of disease will shift. A tropical climate taking over the presently non-tropical climate may also mean higher incidences of diseases, such as malaria, yellow fever and thus will have a major negative impact on health (12)

However, information from several sources indicate that the estimated global temperature increase during the last half century may be lower than it is often claimed to be Also, observation of the extent of the Arctic and the Antarctic ice indicate that they have changed only slightly since 1980 In addition, data indicate that the maximum temperature of the 1900-s occurred around 1950 Therefore, the temperature fluctuated but was still lower around 1990, than it was in 1950. Sensitivity to change in the increased atmospheric concentration of carbondioxide appears to be lower than it is claimed It is further suggested that changes in solar irradiation have been a dominant cause to change in climate as well (13)

THE GREENHOUSE GASES

Following a rapid development in the field of atmospheric chemistry, it was realised that carbondioxide and water vapour are not the only I.R. absorbing constituents, which are present and are accumulating (carbondioxide in particular) in the global atmosphere. Other substances now recognised as greenhouse gases are methane, chlorofluorocarbons, nitrous oxide and tropospheric ozone Present day observation of these gases as well as measurements of air trapped in Antarctic ice which allows carbondioxide, methane and nitrous oxide concentration to be traced back to hundreds or even tens of thousands of years (in the case of methane and carbondioxide) have now firmly established that the currently observed rising trends are a relatively recent phenomenon (within the last 200 years) closely linked to population growth and the industrial revolution - followed by a rapid industrial growth (Table 4). The change in pre-industrial times have been significant, with carbon dioxide increasing by 25%, methane by more than100 %, chlorofluorocarbons being totally man made, not being present in the atmosphere prior to 1930-s (14) The current and past

concentration of most of the greenhouse gases are well known, while research into the sources and sinks of each of these gases is continuing

Table 4

MAJOR GREENHOUSE GASES (G H G) FROM HUMAN ACIVITIES

G H G	Human Source	Relative warming potential (Relative to CO_2)
CO_2	Burning (specially) coal, and biomass, defroestation	1
CH_4	Rice paddy, guts of cattle, termites, landfills, coal production, coal seams, natural gas leaks from oil and gas production and pipelines	24
N_2O	Fossil fuel burning, fertilizers, line stack work, nylon production.	360
CFCs	Air conditioners, refrigerators, plastic foams.	1500 7000

Source: MILLER (G .I) Environmental science Thompson Learning (2002). 542 pp

Atmosphere contains I.R. absorbing components and the I R bands due to them overlap. It is partly because of this overlap that the linear addition relationships of the I.R. intensities do not exist. Consequently, the heat trapping contributions of the individual absorbers do not add linearly (Table 5) Clouds constitute 14% to the trapping with all other species present, but would trap 50% if the other contributors are removed Carbondioxide adds 12% to the trapping of the present atmosphere, i e. it is less important a trapping agent than water vapour or cloud On the other hand, on its own carbondioxide would trap three times as much as it actually does in the earth's surface Many of the trace atmospheric gases viz methane, nitrous oxide have I.R. active modes in the trapping region. These gases may therefore have a direct effect on global temperature quite distinct from that exercised through their possible modification of concentration and major absorbers (15). Molecule for molecule, carbon dioxide is the least effective of the major greenhouse gases, methane by comparison absorbs and re-radiates about 21 times more heat energy, while nitrous oxide is 286 times as effective Chlorofluorocarbons are more powerful, with each molecule absorbing about 15,000 times more heat than molecules of carbon dioxide. However, the over all contribution

of each gas to the greenhouse effect depends on other factors as well One of them is the absorption lifetime - the length of time it remains in the atmosphere before being destroyed by chemical reaction or absorbed into the biosphere or oceans e.g the effect of methane related to other greenhouse gases is diminished to some extent because the atmospheric lifetime of methane is relatively short. With longer-lived gases such as nitrous oxide, chlorofluorocarbons, the withdrawal rate is significantly lower, and new releases have a greater cumulative effect, because it is likely that over the long term each tonne of chlorofluorocarbon as released into the atmosphere will have several thousand times of warming effects of the same amount of carbon dioxide The effect of nitrous oxide can be expected to be several hundred times greater unit for unit, while that for methane will probably be 15 to 25 times great (Table 4)

The other major factor for such comparison is the amount of each gas released into the atmosphere. Since far more carbon dioxide is released to the atmosphere than any other greenhouse gas, it remains the most important single contributor to the enhancement of the greenhouse effect. It is estimated that carbondioxide accounts for about 56% of the global warming potential of the past decade

According to the UN Intergovernmental panel on climate change (IPCC) 3rd Assessment Report, the atmospheric concentration of nearly all Greenhouse gases have climbed more or less continuously since pre industrial time The carbondioxide concentration increased from 280 ppm. in pre industrial time to 368 ppm in 2000 and there is no indication that its rate of increase is slowing greatly or stopping The methane level rose from about 700 ppb in pre industrial time to about 1,750 ppb in 2000 The abundance of N_2O gas from 270 ppb to 314 ppb. The average level of tropospheric ozone increased from 25 Dobson unit to 34 Dobson units (1 Dobson unit is equal to 2.7×10^{10} ozone molecules / cm^3 of air). In contrast, the atmospheric abundanec of most chlorofluorocarbons have been decreasing recently, due to production cutbacks agreed to in the "Montreal Protocol on substances that Deplete the ozone layer " (16) According to Dr R.K Pachauri, Chairman IPCC, a 0.88 m rise in ocean level, well within the prediction for a climate change with double the concentration of carbondioxide from preindustrial levels, would lead to 20 to 60 million "environmental refugees" in India alone (17)

Table 5

CONTRIBUTION OF ATMOSPHERE RADIATION TO THERMAL TRAPPING

Species Involved	Radiations Remaining (%)	Radiation Trapped (%)
All	0	100
H_2O, CO_2, O_3	50	50
H_2O	64	36
Clouds	86	14
CO_2	88	12
O_3	97	3
None	100	0

:e WAYNE (R .P.) Chemistry of the Atmosphere Claredon Press Oxford (1991) 447 pp.

bondioxide:

Carbon dioxide in the atmosphere accounts for only 0- 003 % of the earth's crust It is pid circulation in the biosphere* being removed by plant photosynthesis and added to by t - animal respiration and the decomposition of dead animal matter It is also produced by ictivities of human beings - notably the combustion of fossil fuel (coal, petroleum, natural etc) for energy, (Table 6); and the calcination of limestone for cement**

Though cement is the primary commodity other than fossil fuel mostly included in ventional tabulation of sources of greenhouse gas emission, yet the total greenhouse

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The environment that supports life and sustains various human activities is widely known as the biosphere. The biosphere is a shallow layer compared to the total size of the earth and extends to about 20km from the bottom of the ocean to the highest point in the atmosphere at which life can survive without man made protection device The biosphere contains a complex mixture of carbon compounds in a dynamic equilibrium of formation, transformation and decomposition (18)

Cement production involves the process of calcination in which limestone decomposes to produce calciumoxide and carbondioxide

$$CaCO_3 \rightarrow CaO + CO_2$$

contribution from primary aluminium production appears to be greater than that for cement production on a global basis, and can be tens of times greater in countries with a large primary aluminium industry based on fossil fuel generated electricity Aluminium production is a large green-house gas producing industry, not only because it is a highly electricity intensive industry, but also because of the direct production of carbon dioxide during the reduction of alumina (Al_2O_3) to aluminium metal

$$Al_2O_3 + 3C \rightarrow 4\ Al + 3\ CO_2$$

This reaction results in practice an emission of 1 5 to 2.2 tonnes of carbon dioxide/tonne of aluminium Aluminium smelters consume between 13 to 20 mwh of electricity/tonne of aluminium, depending on efficiency Greenhouse emission from producing this electricity is about 22 tonnes of carbondioxide equivalent/tonne of aluminium, where electricity is produced by conventional coal fired power plant to low level of hydropower (19)

Though carbondioxide is not toxic and does not harm plants or property, but due to the I.R.absorbing properties of carbondioxide (as explained earlier), activities such as combustion of fossil fuel, production of cement, biomass burning, deforestation of tropical forests etc i.e. activities which directly or indirectly add to the concentration of carbondioxide in th atmosphere, add to the "greenhouse effect" and "global warming"

The ratio of the amount of carbondioxide emitted from fossil fuel and that retained i the atmosphere is called the airborne fraction or retention ratio This is critically important t the pace and magnitude of global warming. If the airborne fraction is high, mo carbondioxide emitted into the atmosphere will remain there, and climatic changes are like to occur sooner, than if the airborne fraction is low. Scientists have used recent data worldwide fuel usage; rate of deforestation and reforestation; and increase of atmosphe carbondioxide to obtain an estimate of 0 4 to 0 6 for the historic airborne fraction. In futu an increasing percentage of carbondioxide from fossil fuel emission is likely to remain in t atmosphere This is based on the belief that the top layer of oceans, which serve as primary repository of carbon not retained in the atmosphere, will become saturat Moreover, as temperature rises, the capacity of the oceans to absorb carbondiox represented by the set of ion equilibria given below diminishes

$$CO_2(g) \underset{H_2O}{\overset{kH}{\rightleftharpoons}} H_2CO_3\,(aq) \underset{-H^+}{\overset{k}{\rightleftharpoons}} HCO_3^- \underset{-H^+}{\overset{k}{\rightleftharpoons}} CO_3^{2-} \underset{Ca^{2+}}{\overset{k}{\rightleftharpoons}} CaCO_3 \qquad (20)$$

T able (6)

CARBON EMISSION * FROM FOSSIL FUEL

Fuel	Energy by Content (MJ/kg)	Carbon Content (%)	Carbon Emission * (kg/GJ)	Carbondioxide to Natural Gas
Natural Gas	50 0	75	15.0	1
Oil	42 0	84	20.0	1 3
Black Coal	23 0	65	28 3	1 9
Brown Coal	7 7	24	31.1	2 1

* Carbondioxide emission is generally measured by its weight as carbon

Source: PEARMAN (G I) The Greenhouse effect in NOLLER (B.N.) and CHADHA (M.S) (ed) Chemistry and Environment Common wealth Science Council (1990) 323 pp.

The estimated total release of carbon in the form of carbondioxide for example from oil well fires in Kuwait during '91 was 0 065 GtC - approximately 1% of total annual anthropogenic emissions In India, the emission of carbondioxide is reported to be 0 2 tonnes per capita of carbondioxide emission from fossil fuel as compared to world wide average of 1 1 tonne/capita (21). Table (7)

Models featured in the third Assessment Report on climate change (IPCC) suggest that increasing carbondioxide alone could cause 350 to 890 P_g of carbon ($P_g = 10^{15}g$) to accumulate in terestrial biosphere by 2100. These amounts are equivalent to 22 to 57% of expected anthropogenic carbondioxide emission However, the ecosphere's carbon accumulation may be contained by nutrients, particularly nitrogen, through mechanisms that are not well developed (22).

Scientists estimate that about 6000 million metric tonnes of carbon are pumped into the atmosphere each year in the form of carbondioxide caused by burning fossil fuel such as coal and oil, and by cutting and burning forests However, only about half of this carbondioxide lingers in the air, where it traps heat that could lead to global warming Scientists are puzzled by this mysterious disappearance from the earth's atmosphere of vast quantities of man-made carbondioxide The mystery is, what happens to the other half - the

more than 3000 million metric tones of carbon that is somehow removed from the air each year?

Global hunt for this carbon "sink" is more than just a matter of satisfying a scientific curiosity. Knowing the many sources and sinks of carbon is crucial in predicting how rapidly global warming will occur But a more alarming theory is that vast quantities of carbondioxide now being stored some where on the planet, could be released suddenly by some triggering event with potentially catastrophic results

Table (7)

ANALYSIS OF CARBONDIOXIDE EMISSION OF INDIA ('83-'84)

SECTOR	%
Electricity	33 0
Iron and Steel Industry	9.8
Road and Air transport	8 6
Coal tar	8 1
Non metallic mineral	4 5
Railways	4 3
Cement	4 0
Hotels and Restaruants	4 0

Source· Based on PARIKH (J) GOKARN (S) Climatic Change and India's energy policy option IGDR Discussion paper (1992) 33pp.

Possible sites of a sudden release of carbondioxide include the world's oceans, which for years have been storing dissolved carbon at great depths and the vast forests of northern hemisphere – especially marshy peat land and bogs that together absorb more organic carbon than all other territorial land systems combined

If certain changes occur, such as increased warming, it could cause this carbon to be re-released as carbondioxide, causing a potentially serious situation. Because, then we not only have all the carbon that is already in the atmosphere, but we have this additional carbon that was being taken out over the years, now being put back in, hastening the suspected global warming trend. Though oceans have long been suspected a major depository of carbondioxide, a new study suggests that the sea is taking up far less carbondioxide than is

disappearing from the atmosphere Scientists believe the bulk of carbondioxide created by the burning of fossil fuel is being absorbed by some mysterious process occurring in land, probably in the soil and in some still unidentified plants of the forests of the northern hemisphere. One of the prime suspects of this phenomenon is peat land and bogs, which absorb large amounts in marshy regions, composed mainly of decayed vegetable matter Even though it makes up only 10% of the earth's vegetated land surface, scientists think there is more organic carbon in peat land than there is in the entire ocean system That is why, peat lands over the last few years have become a major focus of research in the field of atmospheric chemistry.

Field studies suggest that increased global warming could cause the peat lands to start loosing their stored carbon by killing mosses - the dominant plant in these areas, which are chiefly responsible for the carbon building. The stored carbon is not only the carbon that was derived from fossil fuel burning over the last several decades, but also the carbon that was stored many hundreds or even thousands of years ago Thus the pool of carbon equals to all the carbon contained in the atmosphere right now (23).

To put the issue of the source and sink of carbondioxide in a slightly different way, a balance may be sought between source and sink of carbondioxide Changes in atmospheric concentration of the gas are a sum of rates of all processes adding carbondioxide minus all those removing it

$$\frac{d(CO_2)}{dt} = C + D + R + S + O - (P + I + B),$$

Where: C is the fossil fuel combustion;

D is deforestation and destruction of biomass;

R is terrestrial plant respiration,

S is respiration from soils and decomposes viz bacteria, fungi, and animals;

O is flux from oceans to atmosphere

P is terrestrial photosynthesis

I is flux of atmosphere to oceans

B is burial of organic carbon and limestone carbon in soils

Of these fluxes, only the increase of carbondioxide and fossil fuel combustion are known to a fairly high degree of accuracy. Most of the other fluxes are uncertain due to insufficient measurements It has been suggested that rising carbondioxide should increase photosynthesis

but this assumes that plant growth to be limited by insufficient carbondioxide This can be true for highly fertilized greenhouse plants, but plants in nature are limited by nutrient deficiencies, and are unlikely to be stimulated by increased carbondioxide.

To stabilize carbondioxide, the equation shows that.

$C + D + R + S + O = P + I + B$ must be followed

Since, neither I nor O can be directly controlled, combustion and deforestation carbon releases $(C + D)$ must be limited to the rate at which storage of carbon in biota soils and sediments can increase $(P + B - R - S)$

Thus to stabilize carbondioxide, increase of photosynthesis and carbon storage in vegetation soils and sediments is needed, along with emission reduction

Two very different (but not mutually exclusive) strategies have been suggested to respond to the problem of the atmospheric accumulation of this anthropogenic carbondioxide. The first approach is an adaptive strategy and it focuses on steps that would minimize the increase and maximize the positive effect of carbondioxide Such a strategy includes land development in such a way as to avoid damage from the increase in sea levels, and shifting agricultural practices to take advantage of the increased photosynthesis.

In contrast, the second approach adopts and seeks to delay or limit the build up of greenhouse gases in the atmosphere Since carbondioxide results primarily from burning of fossil fuel, the strategy necessarily implies a shift in the current pattern of energy use In a way, by adopting this preventive strategy, we could be buying time for designing and implementation of the adoptive action Thus two general approaches to slowing or limiting carbondioxide have been suggested - one as mentioned, relies on altering the pattern of energy use, and the other that employs low energy strategies The first approach involving burning of less coal, oil and gas, and using non-conventional sources of energy, attempts to mitigate the carbondioxide problem indirectly However, of these suggested paths, shifting away from fossil fuel could entail a radical change in the energy foundation upon which current economic activities rest. Under the second approach, either carbondioxide is captured before or after it is emitted to the atmosphere (as detailed later) or the amount of incoming solar radiation absorbed by the earth is reduced via novel schemes Of all these alternatives, currently, change in fuel use pattern has been the most commonly discussed approach for

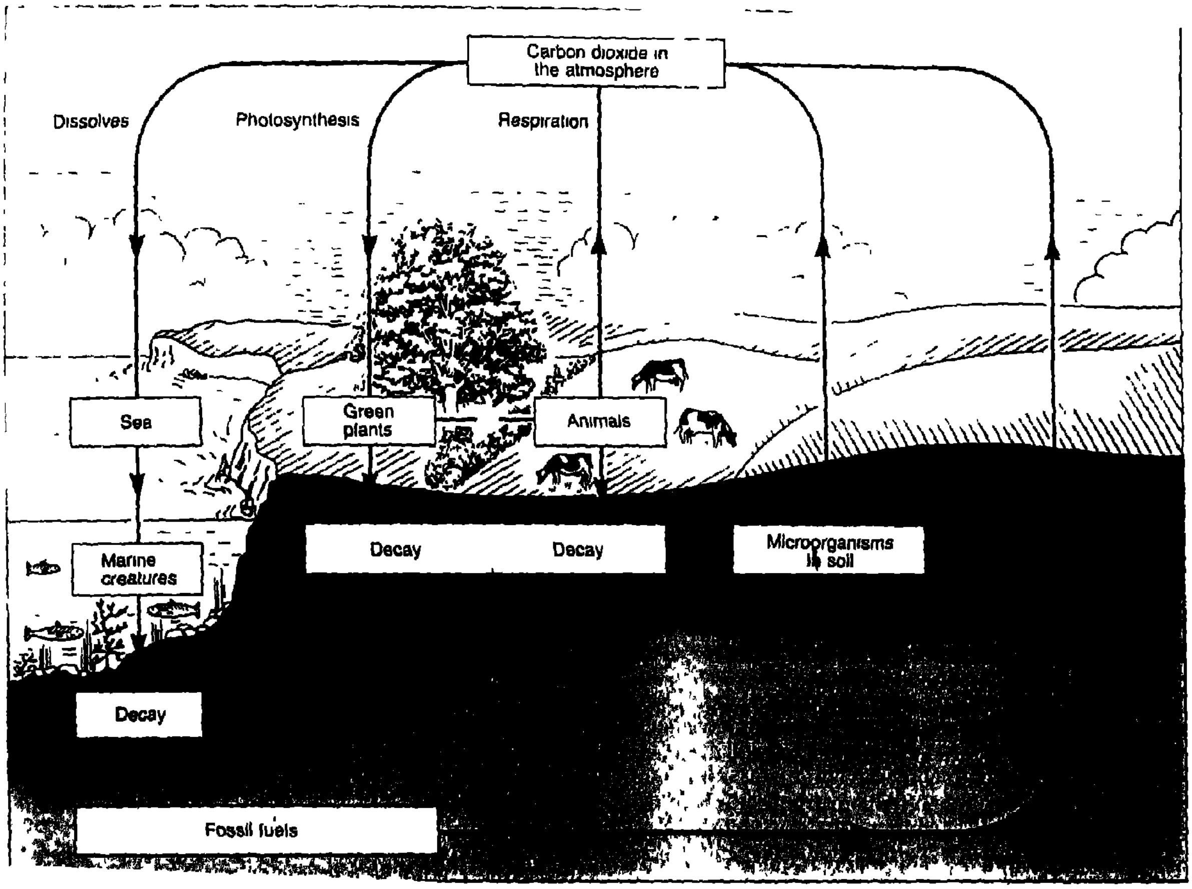
preventing global warming. However, such an approach causes within it several potentially severe effects, e g. using nuclear energy leading to the debate about possibility of radioactive leak, problems due to nuclear waste disposal, etc (24)

World wide, approximately about one-third of all carbondioxide emission comes from coal-fired electricity generating plants. Thus emission levels of carbondioxide can be reduced either by lowering their rate of production or by counteracting the carbondioxide once it has been produced. As far as lowering the rate of production of electricity through coal fire generating processes is concerned, either the current electricity consumption pattern needs to be modified, or other non-conventional sources of energy viz nuclear, solar or other non-fossil fuels are to be used

Power plants traditionally limit carbondioxide emission by scrubbing the stock gas, but there may be other options A typical process plant flue gas contains about 15% by volume of carbondioxide For the flue gas to be an useful source of carbordioxide, the concentration must be increased to about 90% Several processes for doing this have been developed but all of them have significant energy requirements themselves

Apart from CO_2 due to direct burning of fossil fuel, a source of CO_2 is due to the non energy use of fossil fuel – i e consumption of fossil fuel for the manufacture of synthetic mateiral, chemical products viz plastics, fibres, lacquers, varnishes, solvents, fertilizers, bitumen etc In western Europe for example, non energy use represents approximately 12% of the total amount of fossil fuel for non energy production use. Considerable amount of embedded carbon may be released as CO_2 when the life of the product is over, e g detergents which are completely degraded to CO_2 in sewage treatment shortly after their use. For long lived material such as bulk plastic, it depends on the waste management option, whether C is released to the atmosphere within a foreseeable period of time (e.g incineration) or not (e g land fill of plastics), and depends on the type of product when waste treatment occuurs (25)

As far as capturing carbondioxide from the flue gas is concerned, it is now essentially a matter of separating it from the nitrogen that was introduced as a component of the combustion air An interesting idea is a proposal to remove nitrogen from the combustion air, through air separation, before the air enters the plant The resulting use of oxygen or enriched air for combustion would simplify the flue gas separation operation This alternative is suggested to be cheaper than using monoethanolamine to scrub the flue gas to recover the carbondioxide



THE CARBON CYCLE.

SOURCE : MATHEWS (P). ADVANCED CHEMISTRY.
CAMBRIDGE UNIVERSITY PRESS.
(1996), 945 pp.

Having captured the carbondioxide from the flue gas, the question that arises is: What is to be done with it? Four principal ways are suggested for disposing off the unused carbondioxide - as a repressuring fluid for oil reservoirs, by injection: into aquifers; into gas recoveries; into oceans. Of these choices, the ocean injection currently has the greatest appeal

Most of the technologies currently used to produce energy from coal were developed in the '50s and '60s and are approaching the limits of their effectiveness A new generation of coal technology has emerged in Europe and the U.S.A. since the '80s, however, raising the prospect of new coal age with effectiveness in the range of 40-45% and emissions reduced in the case of carbondioxide by up to 30% These "Clean Coal Technologies" can be installed at various stages in the fuel chain or used to convert coal into other more efficient environmentally sound fuel form as follows·

Pre-combustions: Sulphur, methane and other impurities can be removed before coal reaches the boiler, through physical cleaning and chemical cleaning One chemical process, which has shown promise, is the molten caustic leaching, which removes sulphur and mineral matter Biological cleaning, employing microbial and enzymatic techniques to liberate sulphur and ash, has also attracted interest

Combustion: Fluidized bed combustion and advanced "slagging"* combustion are two new advanced technologies used to remove pollutants as the coal is fired

Post Combustion: These gases can be cleaned in the ducting which leads to the smokestack or in advanced version of today's scrubbers.

Conversion: A fourth option outside of the fuel chain is the conversion of coal into other fuel forms. There are five categories of conversion. i) gassification, ii) mild gassification, iii) coal liquifaction, iv) fuel cells, v) magnetohydrodynamics (MHD)

i) In gassification coal is broken into gaseous molecules by bringing it into contact with high temperature steam and oxygen (or air) These gases are purified and the clean gases are burnt. The very hot exhaust is routed through a gas turbine to generate electricity and the residual heat in the exhaust is used to boil water from a conventional steam turbine generator to produce more electricity.
ii) Mild gassification produces gaseous, solid and liquid products by heating coal in an oxygen free reactor

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* The removal of impurities from a mineral by forming molten salts is called slagging operation

iii) Coal liquifaction or a coal-oil coprocessing is a recent development in liquifaction technique which could offer better economics Rather, than liquify coal alone in a complex and expensive process, coal can be mixed with heavy residual oil waste from refineries. The slurry is processed in a cracking unit, sulphur and ash removed before the coal-based liquid is used as fuel

iv) The fuel cell is a coal-based technology, which does not depend on combustion process Gassified coal is used as a source of hydrogen to supply the fuel cell for an electrochemical reaction During this reaction, oxygen and hydrogen from the hydrocarbon fuel are combined to form water, thus releasing chemical energy Japan, U S A and Germany are leaders in research and development of fuel cells

v) MHD processes fire coal at a temperature close to 3000 K The combustion gases are released as a hot stream of highly charged particles (plasma) The electrical conductivity of the gases is enhanced by "seeding" them with special salts (26)

Apart from the power generation plants, and generation of carbondioxide from non energy use, tropical deforestation has also been responsible to some extent for the increase in concentration of carbondioxide in the atmosphere. In 1980, the amount of carbon released to the atmosphere (as carbondioxide) from deforestation was 10 to 50% of the annual emission from fossil fuel. If this trend continues until tropical forests are eliminated, about as much carbondioxide will be released to the atmosphere in the next fifty to hundred years, as has been emitted from world wide combustion of fossil fuel since the start of the industrial revolution On the other hand, if deforestation is halted and replaced with massive reforestation, the net flux of carbon will be reversed The UN-Food and Agricultural Organisation (FAO), using information supplied by individual countries, has earlier estimated that the rate of global tropical deforestation in closed and open canopy forests for the period 1981-1990 was about 17 Mha/yr - approximately 50% higher than the period '70 - '80

Establishment of forests in tropical lands formerly forested and not currently in either agriculture or human settlement could withdraw almost as much carbon from the atmosphere, as will be released if current trends continue unchecked. While such a strategy of reforestation would help stabilize the concentration of carbondioxide in the atmosphere, the solution is temporary Once re-grown, forests no longer accumulate carbon from the atmosphere If the halting of deforestation is accompanied by the substitution of sustainably harvested wood fuel

and if the fossil fuel rise does not increase above current rates, the total net release of carbondioxide to the atmosphere both from fossil fuel and deforestation could be eliminated indefinitely (27)

It has been suggested at some point that, fertilizing the ocean with iron might offset the continuing increase in atmospheric carbondioxide by enhancing the biological uptake of carbon, thereby decreasing the surface ocean partial pressure of carbondioxide and drawing down carbondioxide from the atmosphere Assuming that iron is continuously added to the phosphorous rich waters of the southern oceans, which correspond to 16 % of the world's ocean surface, it was asserted that after 100 years of fertilisation, the atmospheric carbondioxide concentration would be 59 ppm below what it would have been with no fertilisation - assuming no anthropogenic carbondioxide emission However, large uptake of carbondioxide is unlikely to be achieved in practice, owing to a variety of constraints (28)

As far as measurement of concentration of carbondioxide is concerned, one problem that faces atmospheric chemists is how to measure trace amounts of carbondioxide, especially in the presence of water vapour, which interferes with all direct methods of measurement. Japanese scientists of Hokkaido University had found that indium oxide doped with calcium oxide can sense carbondioxide in the air even in the presence of water vapour They prepared indium oxide In_2O_3 by hydrolysing indium chloride with ammonia solution and heating the precipitate to 850 C

The compound was found to become more sensitive when calcium oxide (CaO) was added The detector, (In_2O_3 + CaO) can measure concentration up to 2000 ppm of carbondioxide with as much as 1.8% water vapour at temperatures as high as 573 K Though calcium oxide gave the greatest sensitivity, but oxides of. strontium, barium, nickel, magnesium, and potassium could also be used, with a decreasing order of sensitivity. (29)

However, any realistic strategy to reduce carbondioxide emission must begin with two facts· four fifths of the emission arises from burning fossil fuel - mostly in power stations and vehicles. Secondly, the quarter of world's population living in the developed world is responsible for three fourths of these emissions, and among them, per capita emission of USA and Canada is twice that of Japan and Western Europe. Cuts in emission will require industrialised nations to combine a new culture of energy conservation with research, and alternative methods of energy production that do not involve burning of fossil fuel - such as using of solar, wind power etc. However, one view is that today's urgent need for substantive

carbondioxide emission reduction could be satisfied more cheaply be available carbondioxide technologies than by an immediate transition to alternate sources of energy, so that ample will be available for the alternative energy sources to mature (30)

Recent studies have demonstrated even greater potential for emerging nations such as India, China, Brazil to improve energy efficiency, much of it through improved management and maintenance of machinery But many developing nations argue that the greenhouse problem is a creation of the rich nations and any positive action that the developing nations provide towards a remedy should be paid for by these rich nations either in cash or by donation of advanced energy saving technologies (31)

Methane:

The role of methane in global warming remains unpredictable, since knowledge of methane's multiple sources and of its interactions with other gases is still far from complete. Carbondioxide, the pre-dominant greenhouse gas may be about 200 times more abundant than methane in the atmosphere, but methane is an important greenhouse gas, because a molecule of methane is much more effective than a molecule of carbondioxide in absorbing and radiating I.R energy back to earth's surface It is estimated that the atmosphere lifetime of methane is about 11 years.

Methane is produced by the microbial activities during the mineralisation of organic carbon under strictly anaerobic conditions, e g in waterlogged soils and in the intestine of animals and humans Methane is also released by anthropogenic activities such as exploitation of natural gas, biomass burning, coal mining Most of the biogenic methane is released by ruminants from rice paddies and fresh water swamps and marshes However, estimation of methane emission from rice paddies, swamps and marshes show large variations and uncertainties Methane is also produced by the methanogenesis in oceans and lakes; in water logged tundra soils; decomposition of solid wastes; biogas digestors, processes such as biomass burning*; leaks and venting of natural gas

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* Proper use of biomass for energy, replacing fossil fuel could however reduce greenhouse effect by reducing carbondioxide content of the atmosphere One of the strategies for modernising bio-energy is the production of electricity using advanced Aeroderivative Gas Turbine (AGT) fired by gassified biomass (32)

Methane affects all levels of the atmosphere In the troposphere, it is oxidised by OH to produce primarily carbondioxide and water through a complicated series of steps, some involving the nitric oxide radical NO and the others involving carbonmonoxide CO Because both carbonmonoxide and methane are removed from the atmosphere by reaction with OH, these two gases compete for a limited amount of OH radical As a result, increasing levels of CO can increase methane's lifetime in the atmosphere Some of the hydrogen dioxide radical HO_2 created in the process of oxidizing methane, react with nitric oxide to produce tropospheric ozone, another greenhouse gas.

In the stratosphere, methane has several opposing effects It reacts with chlorine atoms to form methyl radical and inert hydrogen chloride

$$Cl + CH_4 \rightarrow HCl + CH_3 \qquad (33)$$

The methyl radical produced, reacts further·

$$CH_3 + OH \rightarrow \text{products}$$

$$CH_3 + H + M \rightarrow CH_4 + M$$

$$CH_3 + CH_3 + M \rightarrow C_2H_6 + M \qquad (34)$$

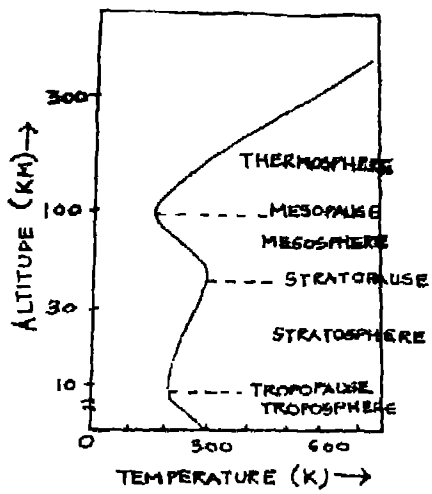

Fig. 3

(The most commonly used names for the different levels of the atmosphere are based on the temperature profile The bottom layer is called the troposphere. Temperature at the troposphere decreases steadily with increasing height up to the tropopause, where there is a marked discontinuity in the temperature gradient; the temperature becoming very nearly independent of height. The height of the tropopause varies from about 15 km in the tropics to about 10 km in higher altitudes

The atmospheric layer above the tropopause is called the stratosphere. Temperature in the lower stratosphere is nearly constant; in the upper stratosphere temperature increases to a maximum at a height of about 50 km. This temperature defines the upper boundary of the stratosphere, the stratopause Temperature decreases in the overlying layer, the mesosphere, until a temperature minimum with the mesopause is reached at a height of about 85 km Above the mesopause in the thermosphere, the kinetic temperature again increases with altitude reaching a maximum value in the region of 1500 -2000 K at the height of several thousand kilometers Above the thermosphere, and demarcated from it by the thermosphere, is an essentially isotherm al region, the exosphere)

The reaction of methane with chlorine takes chlorine atoms out of circulation, thus reducing the destruction of stratospheric ozone. (35)

But methane adds to the destruction of ozone by reacting with electronically excited oxygen atoms produced when ozone photodissocates

$$O_3 + h\nu \rightarrow O_2 + O\,('O)$$

$$CH_4 + O\,('O) \rightarrow OH + CH_3$$

Also, by oxidising to create water and carbondioxide, methane essentially doubles the water content of the stratosphere This in turn amplifies the heterogenous chemistry involved in ozone destruction that takes place on the surface of ice crystals in polar stratospheric cloud

When methane level increases, OH level goes down, and the concentration of two greenhouse gases - tropospheric ozone and stratospheric water goes up The net result is that the indirect effect of methane may increase its global warming potential 50 to 100% (36).

Enormous quantities of methane are reported to be locked up as the clathrate hydrates, such as $CH_4\,6H_2O$ - which are inclusion compounds of ice crystals Gas hydrates below the permafrost of polar region may account for 2 x 10^{15} kg of carbon (three times the carbon content of the atmosphere)- and estimates from the content of seafloor sediments are even larger. Arctic ocean sediments seem likely to be labile and to be exposed to higher temperatures Decomposition over a 100 year period from a layer 40 m thick at about 300 m depth and half way around the Arctic Ocean could release approximately 8 x 10^{12} kg yr^{-1} of methane (37) The oxidation of methane in the stratosphere also provides a source of water vapour in the stratosphere, which in turn causes a temperature increase in the stratosphere due to absorption of I.R. radiation (38).

Recent isotope studies suggest that approximately 100 Tg (1 Tg = 10^{12} g) methane (20% of the total methane source) is of fossil origin - largely from coal, natural gas industries Studies of methane emission from rice cultivation, particularly in Japan, India, Thailand, China show that the emission depends on the ground conditions, especially soil characteristics and vary significantly Where the overall uncertainty in magnitude of global emission from rice cultivation remains large, detailed analysis now suggests significantly lower annual emission than reported earlier (39)

The impact of rice cultivation on global warming has been the subject of study at the International Rice Research Institute (IRRI) at Los Banos, in Phillipines The flooded fields in which 95% of the world's rice is grown emit 25% of the methane which enters the atmosphere annually. Methane is produced by the bacterial decomposition of organic matter in flooded rice soils and enters the atmosphere by three routes· (i) Depending on the season and the time of the day as much as 80% of methane passes from the roots through the plant which acts as a chimney; (ii) smaller amounts bubble up to the water surface or (iii) diffuse slowly into the soil through the water. Most of the diffused methane however is broken down in the soil and floodwater and never reach the atmosphere Changing from irrigated lowland rice cultivation to dry upland farming is not the solution - since even without rice cultivation, much of the wet land areas could be naturally flooded and methane emission is a natural process in flooded soils. Also, farmers cannot quit growing rice to reduce methane emission - rice being one of the important food crops of the world providing more than half the daily food for one out of every three persons on earth. Therefore the aim cannot be a decrease in methane production; but a decrease in methane emission, with increased methane oxidation in the fields - thus lowering the escape of gas (40).

Rice is known to grow under wide range of latitude, altitude, rainfall, ambient temperature, soil pH etc Some efforts are being made in India, at the National Physical Laboratory (NPL) to comprehend the role of soil pH, soil temperature, ambient temperature, chemical composition, type of mineral fertiliser applied etc on the methane emission rate. Information available indicates an area of 4.4×10^6 hectare is under rice cultivation in India. Certain areas yield 2 crops while the rest only one crop in a year, with paddy being grown under pH conditions varying between pH 6 0 - 8.5

On the average, methane budget for India is estimated in the range of 5 to 15 Tg which is a small fraction of the global methane emission attributed to rice cultivation, Table (8)

Table 8

METHANE EMISSION IN INDIA

Category	Global (Mt)	India (% of Global)	India Mt (2004-05) (Projected)
Animals	76	13 6 – 13 7	13.71
Rice	114	28 8 – 29.6	44.39
Biomass burning	65	6 6	5.70
Coal Mines	35	3 8	4 20
Natural Gas	47	0 3	0 31
Landfills	41	6 3 - 6 9	3 29
Total (anthropogenic Components)	378	13 6 -14	71 6

Source: Working paper on global climate change NISTADS (CSIR) 1991

Methane efflux is found to be maximum between 2100 hrs and 0100 hrs (as measured at Delhi region) and is in agreement with observations reported earlier by other workers. A comparison of methane efflux at different regions shows a strong influence of pH on the methane emission rate This may be due to the fact that bacteria responsible for methane genesis grow faster under alkaline environment. Thus soil with lower pH on the contrary, provides a rather less congenial environment for the bacteria responsible for methane genesis in the soil. Low methane efflux values obtained in the paddy fields having rather acidic soil in Dehradun (Uttranachal) support the above conclusion

The cultivation of bacteria seems to be favoured by the water logging conditions at Nadia (West Bengal) High methane efflux is found in paddy grown in low-lying plains of Karnal (Haryana). These paddy fields have puddled soil -- which is impervious to water; which make water stagnant permanently Further, the tube well water used is of pH 8; and the water level in the ground is just a few feet deep. Also, the high yielding variety of rice paddy in this area are 5 to 6 feet high, indicating large root net work responsible for high methane yield (41)

Methane is removed from the atmosphere by reaction with hydroxyl radical OH

$CH_4 + OH \rightarrow CH_3 + H_2O$ A small additional contribution is due to photolysis:

Table 9

METHANE CONCENTRATION AND EFFLUX FOR DIFFERENT REGIONS IN INDIA

Place	Soil pH	Concentration (ppm)	Efflux ($mg\ m^{-2}hr)^{-1}$	Period
New Delhi	6.5 – 8 0	1.5 - 2.1	0.5 – 4 5	Sept'89
Dehradun (U P)	6 0 – 6.5	1 65 – 2 24	0.02 – 0.31	Oct'89
Karnal (Haryana)	8 2 – 8 5	1 63 – 2 71	1 34 – 67 94	Oct'89
Nadia (W.Bengal)	8 0 – 8.5	1.65 – 5.50	2.90 – 8.60	Aug'86

Source Report of the steering Group on Global Change CSIR (1990) 155 pp.

$$CH_4 + h\nu \rightarrow CH_2 + H_2 \rightarrow CH_3 + H$$

and due to reaction with O (ˈO)

$$\dot{C}H_4 + O\ ('O) \rightarrow CH_3 + OH$$

The all-important OH is derived mainly from.

$O\ ('O) + H_2O \rightarrow 2OH$ where O (ˈO) is formed by photolysis of ozone

$$O_3 + h\nu \rightarrow O_2 + O\ ('O)$$

The concentration of OH is limited by the above reaction and by reaction with carbon monoxide CO

$OH + CO \rightarrow CO_2 + H$, where CO itself is derived as by product in the oxidation of methane and from combustion of fossil fuels (42). However, the evidence of increased atmosphere concentration of methane implies a much larger source than previously considered and suggests some natural venting of methane. Thus, the greenhouse warming problem of methane arises from its un-burnt presence in the atmosphere complicated by the phenomenon of poorly understood origin of the gas.

Nitrous Oxide

A sharp increase of tropospheric nitrous oxide (N_2O) abundance has been observed in the recent years, although the rate of increase is considerably less than that of methane

The flux of nitrous oxide in the atmosphere is primarily due to microbial processes in soil and water, and is part of the nitrogen cycle. Until recently, de-nitrification (i e. reduction

of NO_3^- to N_2) has generally been considered to be the major mechanism of nitrous oxide production. Recent experiments have however shown that nitrification (i e oxidation of NH_4^+ to NO_3^-) also plays an important role or may even be the dominant source of nitrous oxide Nitrous oxide is not only produced but also destroyed in the soil and water, whereby the nitrous oxide equilibrium value is established which is determined by parameters such as temperature, pH value etc (43) Although the natural cycle of nitrous oxide is poorly understood, the increased releases are believed to come principally from ammonia land - fertilisers - both chemical as well as from natural waste from domestic animals (44) Exhaust gases from automobiles and industries producing nylon, nitric acid have also been identified as possible significant anthropogenic global source of nitrous oxide. However, the sum of all known anthropogenic and natural sources are still barely sufficient to balance the calculation of atmospheric sink or to explain the deserved increase in the atmospheric abundance of nitrous oxide.

Nitrous oxide may indirectly be contributing to an even greater warming, since through various reactions with other gases in the atmosphere, greater amounts of nitrous oxide may lead to high levels of ozone in the lower stratosphere and upper troposphere. As greater demands are placed on world food supplies, increased use of nitrous oxide producing fertilisers is likely

Nitrous oxide is destroyed in the stratosphere almost exclusively by photolysis and with reactions with O (^{1}O) forming nitric oxide NO No tropospheric sink mechanism of significance for nitrous oxide has been detected so far (45) However, the natural sources and sinks of this trace gas are still not well understood and more research is required before reliable projections can be made for future levels of N_2O

Chlorofluorocarbons (CFCs)

The general term CFC refers to a group of compounds, which are derived either from open chain (aliphatic) or closed ring type (alicyclic) hydrocarbons, where the H atoms are completely or partially replaced by fluorine and/or chlorine. Some CFC compounds also contain bromine. These are commonly called "halons" and are used exclusively as fire extinguishers When all the hydrogen atoms of the hydrocarbon are replaced by a combination of flourine and chlorine or bromine, a "fully halogenated" compound results

The first CFC, R-21 (dichloromonofluoromethane), was developed in 1928 as an

alternative to coolant gases used in refrigerators Soon several CFCs were developed by chemically reacting halogens (flourine, chlorine and bromine) with molecules of simple hydrocarbons, wherein the hydrogen atoms in a hydrocarbon molecule are replaced with fluorine and either chlorine or bromine Being stable, nontoxic, non-inflammable, non-corrosive, the CFCs are used in industries as blowing agents for foams, plastics, aerosol propellants, solvents for cleaning precision electronic equipment, as refrigerants (46) Table 10

Table 10

SOME COMMONLY USED CFCs

Substance	Chemical Formula	Application
R – 11	CCl_3F	Refrigeration, aerosol, foam blowing, solvent, etc.
R – 12	CCl_2CF_2	-do-
R – 22	$CHCl_2F$	-do-
R – 113	CCl_2FCClF_2	Aerosol, foam blowing etc
R – 114	$C\ ClF_2C\ ClF_2$	Refrigeration, aerosol, foam blowing
R- 115	$CCl\ F_2\ CF_3$	refrigeration

Source: TIDE 1(1991) 2

In India we have a total licensed capacity for CFC production of over 20,000 metric tonnes/year However, the actual production is about 25% of this capacity We do not have production facilities for halons, and meet its requirement by importing these substances to the tune of 300 metric tonnes/year 10% of the CFCs in India are used in aerosol, 5% in blowing, 83% in air conditioning and refrigeration, and 2% in other activities (47)

Various flourine compounds including CF_4 and C_2F_6, also known as CFC -14 and CFC -116 respectively, are produced during electrolysis of alumina (Al_2O_3) dissolved in cryolite (Na_3AlF_6) bath. Average CFC-14 and CFC-116 emission are found to be equivalent to the greenhouse contribution of about 15-20 tonnes of carbondioxide/tonne of aluminium. With reported atmospheric residue time in excess of 10,000 year and with strong absorption band near $8x10^{-6}$ m, CFC-14 and CFC-116 may be the most potent greenhouse gas being emitted in large amounts. Not only do they have a very large global warming potential, they also cause an essentially permanent alteration to greenhouse warming (48)

One study estimates that the direct effect of CFCs should increase temperature by

0 3°C.if annual production were maintained at 1973 level Infact, the growth of green house gases peaked in the early 1980-s, at about 0 5 watt / sq meter / decade but declined to aboute 0 3 watt / sq meter / decade, primarily because of reduced emission of chlorofluro carbons whose production is now being phased because of their destructive effect on stratospheric ozone due to the Montreal Protocol* (49) Work is under way world over, India included, to find alternatives to CFCs A few partially halogenated CFCs, hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons so called (HFCs) have been developed. However, there are reports, which state that the HCFCs and even the HFCs may also have significant potential to contribute to greenhouse warming

Ozone:

Ozone (O_3) absorbs I.R. as does carbondioxide and contributes directly to the greenhouse effect In addition, a decrease in total ozone of the stratosphere, resulting in an increase of ultraviolet (U V.) radiation reaching the upper layers of the sea, may cause death of phyloplanktons. If this happens, the marine biomass will be less able to absorb the carbondioxide dissolved in the water, reducing oceans' effectiveness as a carbon sink The effect of this would be to have more carbondioxide in the atmosphere

In its natural state, ozone occurs in layers, which have a maximum concentration at approximately 25 km above the surface of the earth It is constantly being created and destroyed through natural chemical cycles triggered by U V radiation (51)

$$O_2 + h\nu \rightarrow O + O$$

$$O + O_2 + M \rightarrow O_3 + M$$

(M is a third particle acting as a collision partner) Ozone itself is further photodissociated.

$$O_3 + h\nu \rightarrow O_2 + O$$

The resulting O can in turn break down O_3

$$O_3 + O \rightarrow O_2 + O_2$$

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*In September 1987 about 40 countries of the world signed at Montreal Canada, the "Protocol on Substances that Deplete the Ozone Layer", popularly known as the "Montreal Protocol" On June 19, 1992, India also signed the Montreal Protocol This protocol outlined a procedure for restriction by 1990 of global emission of CFCs to 50% of the 1986 value level, with provision for reviewing the restriction every 4 years (50)

Atmospheric ozone varies considerably both in space and time. It is now accepted that the concentration of tropospheric ozone is increasing due to photochemical process Methane, carbonmonoxide and nitrousoxide also play an important role in this context. This increasing concentration of ozone and reaction with OH radical are of prime importance for the ozone chemistry in the troposphere However, since the life time of ozone molecules in the troposphere is comparatively short (a few weeks), considerable spatial variations occurs and it is difficult to assess the possible global change of ozone (52).

Deforestation and admission of land to pastures or other uses could alter regional and global ozone budget. Since elimination of forests can dramatically reduce emission of biogenic hydrocarbons, which serve as a chemical ozone sink (53)

Aerosols.

Aerosols are tiny particles in the atmosphere that cause haziness They may be natural or anthropogenic - the latter being the ones that are usually considered as pollutants - consisting mainly of H_2O, H_2SO_4 and sea salts Aerosols are important in the atmosphere as nuclei for condensation of water droplets and ice crystals, as participants in various chemical reactions, as absorbers and scatters of solar radiation.

They therefore influence the radiation budget of the earth-atmosphere system, and thus along with the greenhouse gases, affect the climate on the surface of the earth. However, their relative short and irregular lifetime have made it difficult to quantify their contribution to regional and global radiative budget

The radiative effect of the aerosols can be explained as follows: Non-absorbing aerosols increase the albedo* of the atmosphere and reduce the amount of solar radiation that reaches the surface. If the aerosol absorbs in the short-wave range of the spectrum, energy is directly transferred to the atmosphere If the aerosol absorbs and consequently also emits radiation in the I.R. part of the spectrum, energy is withdrawn from the upper troposphere due to emission to space, but the greenhouse effect near the surface increases The net effect depends on the ratio of the absorption coefficient in the visible and the I.R and also in the albedo of the surface and the altitude of the aerosol layer.

* Albedo is the whiteness of, or degree of reflection of incident light from an object or material It is defined as the proportion of incoming solar radiation that is reflected. Snow and cloud surfaces have a high albedo, because most of the energy of the visible solar spectrum is reflected. Vegetation and sea have a low albedo, because they absorb a lower fraction of the energy. Cloud is the chief cause of the variations in the earth's albedo (54).

The principal difficulty encountered when trying to assess the possible climatic effects of increasing aerosol concentration in the atmosphere due to anthropogenic activities is associated with the fact that the residence distribution of the aerosol is very variable - the residence time being dependent on their particle size, the height at which injection occurs and condensation process by which the aerosols are washed out Also, the radiative character of atmospheric aerosols vary significantly in space and time due to many different reasons Tropospheric aerosols which have lifetime less than a week, and extremely patchy horizontal spatial distribution, may, in fact cool the climate through this direct radiative effect by an amount comparable to the warming expected from a doubling of carbondioxide (55)

Temporary changes in climate due to increasing aerosol concentration in the stratosphere from volcanic eruption must be well understood in order to distinguish between these and possible changes due to anthropogenic emission of both gases and aerosols (56) Thus, substantial variation of the greenhouse effect may be expected to occur during periods of volcanic activity arising from changes in gaseous composition and in aerosol content In high volcanic activity conditions, it is natural to expect a heightened concentration in the atmosphere of such volatiles such as sulphur dioxide (known to have strong absorption band in the long wavelength spectral region), water and the presence of dense haze, layers of sulphuric acid solution, etc (57) Thus temporary change of climate due to increasing aerosol concentration in the stratosphere from volcanic eruption must be well understood in order to distinguish between these and possible changes due to anthropogenic emission of both gases and aerosols

The chemical composition of the aerosols varies considerably depending on their source - major aerosol types identified beings

i) Coarse mechanically produced mineral dust viz quartz, silicious clay, with particle size greater that 3×10^{-6} m

ii) Coarse oceanic sea-salt particles e.g. water and sea spray particles, particle size being less than 3×10^{-6} m

iii) Fine and medium sized products of - gas to particle conversion, particle size being less than or equal to 1×10^{-6} m

v) Volcanic ash of varying composition, with particle size being less than or equal to 1×10^{-6} m. (58)

The major source of anthropogenic aerosols are: burning of fossil fuel and industrial activity which produces particles directly (i.e. soot, fly ash etc.); large quantities of oxides of nitrogen and sulphur which are eventually converted to nitrate and sulphate products; and mineral aerosols as a result of poor land-use practices. (59)

Sulphates have been recognised as the dominant contributor to trosposphenic aerosols over and near industrial areas Smoke aerosols such as soot (black carbon), a product of atmospheric combustion of fossil fuel, biofuels and burning outdoor of biomass (wood, cowdung etc.) may have a similar role over and near tropical continental areas. The production of both sulphur and smoke aerosols from human activities is expected to have greatly intensified during the last century However, so called white aerosols arising mainly from sulphur in fossil fuel are highly reflective and thus reduce solar heating of the earth. (60) Thus, the recent estimates of the contribution of anthropogenic emission of sulphate aerosol to atmospheric radiation balance appears to be similar in magnitude but opposite in sign, to the effects of the increase in the atmospheric greenhouse gases over the last century The global effect of aerosols from smoke adds further to this effect. Thus, their increase over the last century may explain why the warming observed over this period is at the lowest limit of that indicated by climate models for greenhouse gases (61) But the question is do we allow acidification of the atmosphere (leading to such phenomenon as the dreaded "acid rain") to protect us from global warming?

Feedback Processes:

As was stated earlier (page 2), along with the atmospheric emission resulting from various human activities, positive "feedback" effects add to the global warming phenomenon. Whenever a change in the environment causes a deviation from the desirable condition, there must be a receptor that detects this change. Once the undesirable change is detected by the receptor, a signal must be sent along some sensory path-way for a central response selector, which has both a memory of the most desirable condition and an ability to select the best method for returning the system to that desirable condition. This relaying of information from the effector to back to the receptor is appropriately called "feedback" A feedback, that tends to return the system from a swing in certain direction back to the desired normal condition, is called the negative feedback On the other hand, a feedback that causes the system to run away from the desired condition towards a complete loss of control is called a positive

feedback. Thus, negative feedbacks tend to return the system to some desirable rest condition and positive feedbacks tend to cause the system to run away from the rest condition (62) As far as the phenomenon of global warming is concerned, a negative feedback therefore works to reduce the severity of global warming by reducing the concentration of carbondioxide and other greenhouse gases in the atmosphere. Such "feedbacks" include cloud covers and snow covers that increase the reflectivity of the earth and reduce the energy reaching the surface Another important negative feedback has been assumed to be stimulation of the fixation and storage of carbon by terrestrial plants by the increase in carbondioxide in the atmosphere A positive feedback will speed the warming of the earth· the warming makes the warming worse. They include any effect that increases the release of carbondioxide or other I.R. absorbing gases into the atmosphere, or otherwise increases the retention of the heat on the earth's surface (63)

A positive feedback for example, results due to extra surface warming leading to more evaporation - since water vapour is a greenhouse gas. A second feedback is linked to the observation that, a surface warming will lead to reduced snow cover and less sea ice This would reduce the amount of solar radiation reflected and thus increase the warming at the earth's surface

Due to clouds, which play a major role in earth's radiation balance, and which reflect a significant amount of the incoming solar radiation, increased evaporation and increased levels of atmospheric water vapour are likely to lead to increased cloud cover Low-level clouds are known to have a net cooling effect due to the reflection of the incoming sunlight, and thus can be expected to decrease any greenhouse warming But high level (cirrus) clouds are known to be relatively more efficient in trapping I R. radiation, leading to increase of the surface warming

Yet another feedback invites the role of the stratosphere and the stratospheric ozone The presence of CFCs, as is known, reduces the stratospheric ozone layer and thus reduces the amount of incoming solar radiation trapped by the stratosphere, allowing this radiation to reach the earth's surface and then add to any tropospheric warming. The magnitude of this warming, however, will be small, compared to the warming due to increase in greenhouse gases in the lower atmosphere. In addition to the above there may be a range of other, perhaps minor feedback processes (64)

WHAT IS BEING DONE TO REDUCE GLOBAL WARMING AND THE GREENHOUSE EFFECT:

International Scene

The United Nation General Assembly's first debate "Our Common Future", held in October '87, was marked by references of global warming dramatised by a plea from the President of the Republic of Maldives for international action to prevent the "disappearance of his nation" beneath rising sea levels - an effect of global warming (65) By then, the issue of global warming had ceased to be a scientific and environmental issue only, and had started to perplex the international community in general Shortly, before this UN Conference, in 1985, the "Villach Conference" on the "Assessment of Role of Carbondioxide and Greenhouse gases in Climate Variation and Associated Impacts" was held, and by 1986, the Advisory Group on Greenhouse Gas (the AGGG) was established jointly by organizations such as The World Meterological Organisation (WMO), United Nations Environmental Programme (UNEP) etc (66). The debate concerning the necessary steps to limit greenhouse gas emission resolves around two basic questions. What will be the resulting climate change due to global warming, and what will be the impact of that change? To address these two questions - two Inter- governmental Panel on Climate Change (IPCC) working groups were established The first working group was assigned the task or identifying the changes in climate resulting from increased concentration of the greenhouse gases The second working group was required to assess the environmental and socioeconomic consequences of climate change Reports were issued by both groups in 1990, with an "update" in 1992 (67)

The 'Kyoto Protocol'

In June 1992, United Nations Conference on Environment and Development' 92 (UNCED'92) held the Earth summit at Riode Janeiro, Brazil, commonly called on "Rio Conference", where the "UN Framework Convention for Climate" was propose. Of the 106 nations which assembled at the Rio Conference, the developed nations committed themselves to reduce their emission of carbon dioxide and other greenhouse gases, by the year 2000, to the 1990 levels. However, the convention did not require countries to reach this goal

In December 1997, more than 2,200 delegates from 161 nations met at Kyoto, Japan,

to negotiate a new treaty to help slow global warming The resulting treaty would require 38 developed nations to cut greenhouse emission by 2012, to an average of approximately 5.2% below the 1990 level. However, the developing countries were not required to make any cuts in their greenhouse gas emission, until the second stage of the treaty (68). The treaty also left vague, the rules of exactly how courtiers could achieve this reduction For instance, there was no clarity about how much could be relied on carbon" sinks" or on "emission trading " – i e on the extent to which a country can 'buy" emission reduction credits from a other country Further, it was also unclear, as to how much help the developing countries would get to cope with climate change The protocol mandates that developed countries transfer money and technology to help the developing countries make the transition to cleaner energy production (69)

Although USA has not ratified the "Kyoto Protocol", but the UK government has started to deliver on its promise, and it has now become the first large industrial economy to announce caps on emission of carbondioxide by large industrial operations such as , power stations, oil refineries and cement works. It has fixed an average reduction target by 16% by 2012 and a further reduction of 10% each decade till 2050 (70) Russia on the other hand, has not only refused to ratify the Kyoto Protocol, but has plans to almost double its coal production by 2020 to feed domestic energy needs, while exporting natural gas This could in fact lead to sky rocket the country's greenhouse gas emission, well past the Kyoto Limit (71).

The Indian Scene:

Ecological and economic effects of global warming may vary from country to country and consequently, response needs to be tailored to specific requirements and situation By virtue of being placed fifth on the list of the top greenhouse gas emitters of the world, (Table 11), India has the responsibility to formulate strategies that could be acceptable to other developing countries faced with the same choice as India's It is clear that given India's lack of oil, India will have to continue to depend on her more abundant resource of coal for energy For this reason, out of the country's concern towards global warming due to increased concentration of carbondioxide, India hosted a "clean coal" conference in January '92, (the first such conference being hosted in December '90, by another major coal using country – China.)

With an economy, large part of which is agriculture – based, India cannot cut back either on paddy cultivation or on cattle population Also, until CFC substitutes are commercially viable, there is little possibility of the country cutting back on the comparatively small amount of CFCs used in industry Thus, an important component of the strategy for India may be a much greater effort at curbing the rate of deforestation.

The Government of India's Ministry of Environment and Forests have set up an "Expert Advisory Committee on Global Environmental Issues" (EAC), which also has an EAC programme on the "Total Global

TABLE 11

THE TOP FIFTEEN GREENHOUSE GAS (G.H.G) PRODUCING COUNTRIES

RANK	COUNTRY	TOTAL NET ADDITION (1,000 metric tones of C equivalent x10^3)	%SHARE OF GHG INCREASE	NET PER CAPITA ADDITION (kg. Of C)
1	USA	920	17 0	3 8
2	Russia	700	13 1	2 5
3	Brazil	460	8 5	3 3
4	China	410	7.6	0.4
5	India	250	4 6	0 3
6	Japan	200	3 7	1.6
7	Indonesia	150	2.7	0 9
8	Germany	140	2 7	2 4
9	U K	130	2 5	2 3
10	Italy	100	1.9	1 8
11	France	99	1 8	1 8
12	Canada	88	1.6	3 4
13	Mexico	77	1 4	0.9
14	Poland	76	1 4	2.0
15	Columbia	67	1 2	2.2

Source: HAMMOND (E R); MOOMAW (W) Nature 317(1990) 705-706

Warming". In the field of scientific research, though India's contribution on research on global climate change is not substantial, but it does exist in a limited manner At the international

level, India participates in International Geosphere- Biosphere Programme; and is a party to the UN framework convention on climate change (UNFCCC) The objective of the UNFCCC is to stablise the Greenhouse gas concentration in the atmosphere at a level that would prevent this dangerous human induced interference with the climate system. The Ministry of Environment and Forest of the Government of India is the executing and the implementing agency of the Project. A National Sheering committee under the chairmanship of Secretary Ministry of Environment and Forest oversees the implementation of the Project at the national level Environmental studies related to climatic changes have been undertaken by the Council of Scientific and Industrial Research (CSIR); India Meteorological Department, selected universities, Indian Institutes of Technology (IITs) etc (72).

The CSIR, with its forty laboratories of multidisciplinary character and other infrastructural facilities, has a major role to play on global climate change - as far as India is concerned CSIR constituted a steering group for global change in 1989, to identify plans and priorities; to lay down milestones and to monitor progress for activities in these areas The CSIR under its programme on global change had constituted a task force consisting of National Physical Laboratory (NPL); National Environmental Engineering Research Institute (NEERI); National Metallurgical Laboratory (NML), Indian Institute of Petroleum (IIP), Central Mechanical Engineering Research Institute (CMERI); to oversee the following areas·

i) CFC substitutes and alternate technologies;
ii) Greenhouse gases and global warming;
iii) Sea level monitoring and modeling,
iv) Air-sea interaction;
v) Medical effects and related aspects;
vi) UV-B and temperature effect on ecosystem; aquatic system and individual materials.
vii) Earth system history,
viii) Mathematical modeling for global change

The strength of India's scientific programme lies in the availability of its own remote sensing satellite with its remarkably high resolution, existence of three rocket ranges and the high altitude balloon flight range of Hyderabad (73)

The developing countries have often pointed out that it is "unfair to equate luxury emissions" of CFC (used in air conditioning and refrigerators) which cannot be absorbed, with "survival emission" of methane (produced through paddy cultivation and by cattle), which are absorbed to some extent. The plea from the developing countries has thus been, to give these three main gases varying weight age while determing a country's potential to harm the world's climate (74).

Studies have shown that although not required under the Kyoto Protocol, several developing countries, India included, are already taking action that have positive impact for global climate change mitigation. Brazil, China, India, Mexico, South Africa and Turkey have together for example, reduced the growth of the greenhouse gas emission by about 300 million tones/year over the past few years.

Growth in energy related carbon dioxide emission in India was reduced over the last decade through economic restructuring, enforcement of existing environmental legislation and programme of renewable energy As a result, in the year 2000 alone, energy pollution initiatives have reduced carbon emission growth reportedly by 18 Mt which is approximately 6% of India's gross energy related carbon emission

Recent discovery of the largest natural gas reserve in the Krishna – Godavari basin in Andhra Pradesh, equivalent to about 1.2 billion barrels of crude oil, is about 40 tonnes greater than the Bombay High reserves and would further reduce energy related carbon emission in India. The new found reserve can meet the demand of gas in India over the next 100 year – and spare time, sufficient enough to allow scientists to search for other clean energy options

The Ministry of Environment and Forest of the Government of India has retained the National Environmental Engineering Research Institute (NEERI) at Nagpur to prepare a document on the 'Greenhouse Gas Inventory Estimation of Waste Sector' Accordingly NEERI carried out field studies in various cities and presented four reports in the form of Status, Activity Data, Preliminary Inventory and Final Inventory. According to NEERI the methane emission value form domestic, industrial waste water and domestic waste were 399 Gg, 72.301 Gg and 8.27 Gg/year respectively in the year 1999 (75) To tackle the problem of global warming form a different front, in order to study the effect of ozone change in the troposphere because of natural and manmade activities and to monitor vertical distribution of ozone and humidity at surface and in troposphere, the Department of Space of the

Government of India, through the Physical Research Laboratory Ahmedabad, plans to send balloon flights every fortnight (76)

The developing world is suggested to be responsible for most of the recent deforestation and forest fire induced carbondioxide emission. That may be true locally, but it is only part of a larger picture. Most of the human modification of the landscape over the past few centuries has recurred in the temperate latitudes by converting forests and grasslands to highly productive cropland and pastures emitting large amount of carbon dioxide in the atmosphere Thus, in totality, compared to emission due to current and historic land use change and fossil fuel emission in temperate latitude, emission from the developing world is still small However, tropical forests, soils, and peat lands are large carbon pools and strengthening of the management regime to save against wild fires is urgently required, since catastrophic events such as forest fires can release carbon in a particular year (77)

A Mirror to Cool the World

Until very recently, climate scientists mostly dismissed the idea of engineering as one way out of the problems of global warning, since information on the likely cost, effectiveness and potential ecological impact of such schemes were scant But that view is starting to change, and the view of the engineers, that they can reduce global warning by 'shading' the planet, is being considered

The technologies come in two forms· one aims to head off the greenhouse effect by capturing carbon dioxide and storing it out of farm's way – either in geological structures such as old oil wells, or deep in the ocean; and the other, allows carbon dioxide to accumulate in the atmosphere but puts the brake on warming, either by 'shading' the earth from the sun or by engineering the environment to reflect more solar radiation back to space by·

- Changing the Planet's reflectivity – i e. its 'albedo' This would be the fastest way to half the global warming, and ideas on how to do it started in mid 1960s. Methods then suggested were : spreading billions of small reflecting objects such as white golf balls accross the tropical oceans.
- Mimicking volcanic eruption by throwing light reflecting sulphate particles into the stratosphere.
- Putting strips of metals or specially made optical resonant seatterers which reflect light of particular wave lengths into the stratosphere

- Floating in the stratosphere a million tonnes of tiny aluminum balloons (about 4 mm diameter) filled with hydrogen gas.
- Assembling a giant mirror in space – a thousand km accross and park it between the sun and the earth so that it reflects solar radiation away from our atmosphere Some 3000 tonnes of shield could compensate for a doubling of carbondioxide levels The cost of this would run into hundreds of billion dollors, but would be a fairly permanent solution.
- A more down-to-earth option, based on the old idea of 'seeding' clouds to make rain has been, to make clouds white , by adding a large number of particles to the cloud such that droplets packed in the clouds boost their whiteness and reflectivity

However, apart from practical problems connected with altering albedo, tinkering with something as crucial and poorly understood as solar radiation could have dramatic and unforeseen consequences for the global climate and life supporting spheres

Thus the mega engineering projects for removing green house gases (mainly carbondioxide) from the atmosphere are.

- Zero emission and more plants involving extraction of carbon dioxide from chimneys and burning it in the ground or deep ocean
- Cleaning up fuel – stripping carbondioxide from flue gas and burying it in the ground or ocean.
- Plankton bloom – encouraging 'Plankton' to grow and absorb carbondioxide
- Windmill extraction – waft air over chemicals to remove carbon dioxide
- Giant Mirror – 1000 km diameter parked between earth and sun
- Floating 4 mm diameter reflective aluminum balloon in the stratosphere.
- Spraying sulphate particles into stratosphere by airplane
- Spray turbine – hundreds dotted accross the oceans, flinging salt spray into atmosphere to whiten clouds. (78)

'Contraction and convergence' (C & C) is however now emerging as a plan for controlling emission of greenhouse gases. Since carbondioxide and other greenhouse gases linger in the atmosphere for a century or more, staying below the ceiling of less than 450 ppm would mean drastic cuts in emission over the next 50 years Industrial nations have so far done most of the polluting. The USA emits currently, 25 times as much carbondioxide /head

as India But if pollution is to be rationed, this can not go on So under the C&C proposal, national emission will converge yearly, towards some agreed target, based on each country's population So, in effect by a target date, every citizen of the world should have an equal right to pollute.

In September 2002, Britain has started a new investigation into reducing of a technique called 'carbondioxide capture and storage' The technique prevents carbondioxide emission from power stations being released into the atmosphere, by storing it underground in depleted oil and gas wells (79)

The average global citizen is responsible for pumping about a tonne of carbon into air each year. To present dangerous climatic change, the world has to reduce this figure around 0.3 tonnes/head (80).

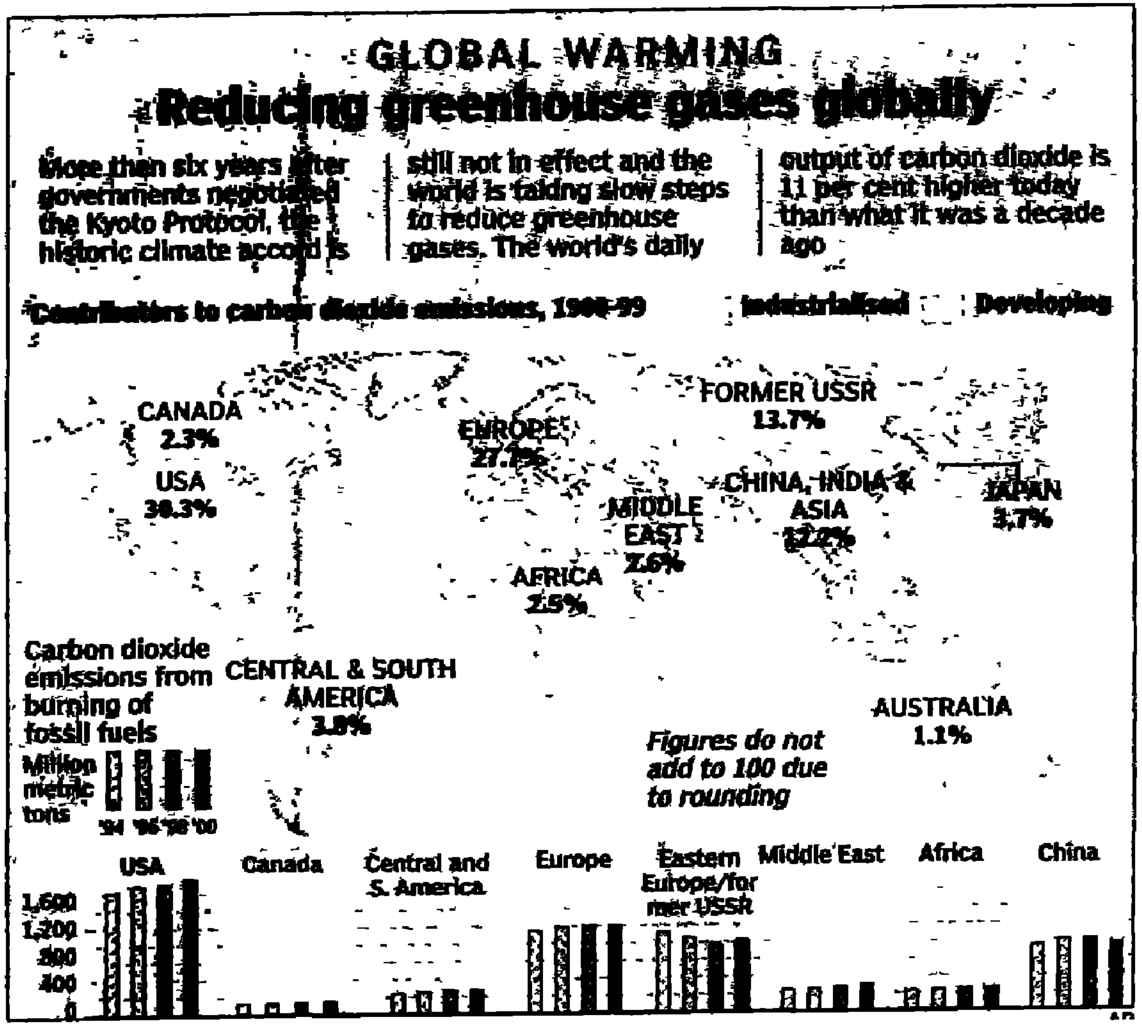
Role of Lifestyle and Service Consumption in Reducing Greenhouse Gases

Despite the fact that lifestyle, in particular goods and services consumption play a major role for greenhouse gas emission, specially for the affluent section of the society, these issues are often inadequately addressed. As a consequence, recommendations for reducing personal emission concentrate on the aspect of fuel use only, missing the more important issue of reducing goods and services consumption as an effective way to abate climate change Australia has recently published a household greenhouse gas emission questionnaire and has suggested the following for reducing greenhouse gas emission arising out of personal reasons·

- Reuse and recycle rather than throwing out
- Buy locally grown food rather than packed imported food.
- Eat fruit, vegetable, bread and cereal rather than meat product
- Install solar hot water system rather than using electrical heating systems.
- Use surface transport instead of flying
- Plant trees.
- Increase the quality of life rather than standard of living (81)

Concluding Remarks

Climate change is real, the causal link to increased greenhouse emission is now well established Globally, the 10 hottest years on record have occurred in 1991 In the past century, average temperature of the world has risen by about 0.6^{0}C. In that same period,



SOURCE: HINDUSTAN TIMES JUNE 15 (2004).

global sea level has risen by about 20cm – partly from melting of land ice and partly from thermal expansion of the ocean Ice caps are disappearing from many mountain peaks and summer and autumn arctic sea ice has thinned by up to 40% in the recent decade In less than 200 years, human activity has increased the atmospheric concentration of greenhouse gases by 50% relative to preindustrialised levels. At about 372 ppm, today's atmospheric carbondioxide level is higher than at anytime in the last 420,000 years Current models suggest that stabilizing carbon dioxide levels at about 550 ppm by 2100 could reduce flooding frequency by some 80 to 90% along the some most vulnerable parts of Indian and Bangladesh coastline as compared with scenario of continuing growth in consumption of fossil fuel.

Some climate change can always be attributed to natural cycles and disturbances in the earth's climate system, but the general warming over the last century can not be explained without involving human induced effects (82)

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